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Supersonic Flow of Air Around Corners

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ABERDEEN PROVING GROUND, MARYLAND

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SUPERSONIC FLOW OF AIR AROUND CORNERS

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ABSTRACT

Problems arising in the field of supersonic aerodynamics frequently involve "Prandtl-Meyer" flows. These flows permit exact mathematical solutions,[1] and tables describing such flows are available. However, most of these tables suffer from one defect or another. Thus, some of them are based on a value of γ of 1.4, which is not sufficiently accurate for many investigations. Others are either not extensive or accurate enough. In the present table care has been taken to avoid most of these major defects; the calculations are based on $\gamma = 1.405$, and they have been carried out with an accuracy deemed satisfactory for most purposes.

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1 For a treatment of such flows consult, for example, R. Sauer, Theoretische Einführung in die Gasdynamik, Berlin, 1943.

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INTRODUCTION

The plane, steady, irrotational flow of a perfect gas in the neighborhood of a corner O, Figure 1, is composed of 3 parts: the undisturbed flow, having the velocity $\vec{q}_o$ to the left of the initial characteristic C_o, the flow about the corner O, between C_o and the final characteristic C_f, and the turned flow, with $\delta_f = \omega$, and the velocity $\vec{q}_f$, to the right of C_f. It is the "Prandtl-Meyer" flow between C_o and C_f which is of interest here.

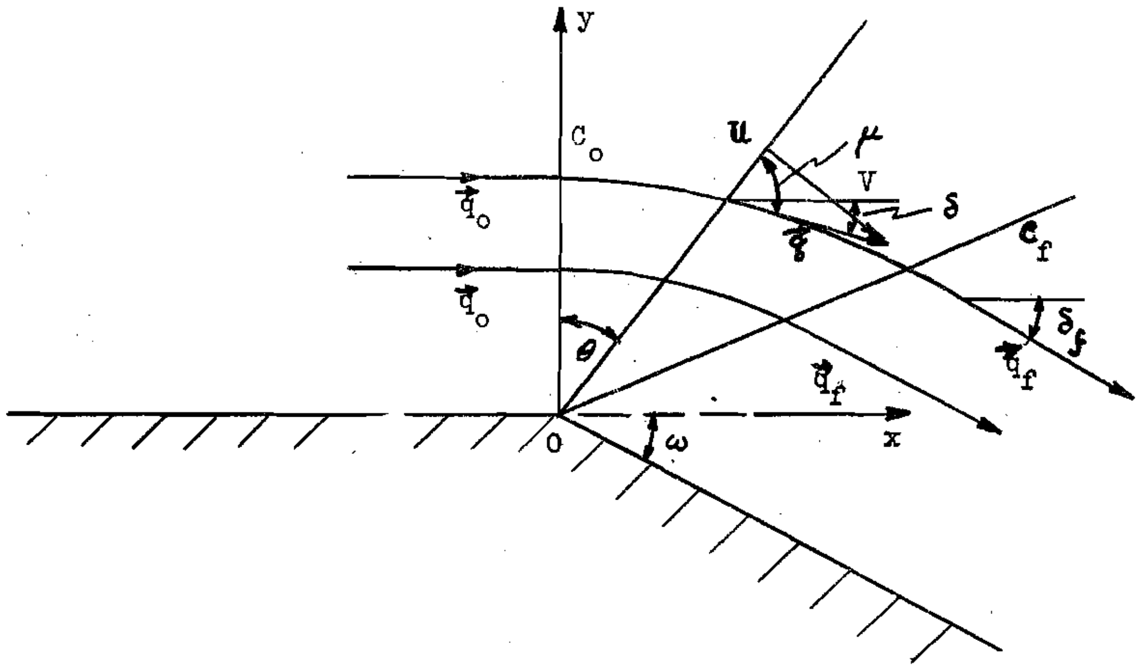

Figure 1. Flow around a corner.

This flow satisfies the partial differential equation

$$(a^2 - u^2)\,\phi_{xx} - 2\,u\,v\,\phi_{xy} + (a^2 - v^2)\,\phi_{yy} = 0, \qquad (1)$$

where $\phi(x,y)$ is the velocity potential, $\phi_x = u$, $\phi_y = v$ are the components of the velocity $\vec{q}$ in the x,y directions, respectively, $\vec{q}$ being measured in terms of the velocity c of efflux into vacuum, and a is the local speed of sound, also measured in terms of c. The velocities a, c, and $q = (u^2 + v^2)^{\frac{1}{2}}$ are related by means of Bernoulli's equation

$$q^2 + 2\,a^2/(\gamma - 1) = c^2, \qquad (2)$$

with $\gamma = 1.405$ denoting the ratio of specific heats of air.

The flow around a corner is characterized by the fact that the velocity vector $\vec{q}$ is constant along the radial lines lines from the corner; see Figure 1. It is thus more appropriate to describe the flow in polar coordinates r, θ, rather than in Cartesian coordinates x,y. In terms of the new coordinates we have the potential function $\phi = r\,\Phi(\theta)$, for the radial and transversal velocity components U, V: $U = \partial\Phi/\partial r = \Phi(\theta)$, and $V = \partial\Phi/r\,\partial\theta = \Phi'(\theta)$. Equation (1) becomes

$$(a^2 - V^2)(\partial V/\partial\theta + U) = 0.$$

Now in supersonic flows the velocity component perpendicular to a Mach line always equals the local speed of sound. For flows around corners, then, $V = a$, so that equation (2) becomes

$$(k^{-1}\,\Phi')^2 + \Phi^2 = 1, \tag{3}$$

with $k^2 = (\gamma - 1)/(\gamma + 1)$.

If the free stream Mach number M_o is unity, so that $q_o = k$, then the angle θ, which is counted clockwise from the initial characteristic C_o, is initially 0, and, clearly,

$$U\ (0) = \Phi(0) = 0. \tag{4}$$

The solution of equation (3) with the initial condition (4) is obviously

$$\Phi(\theta) = \sin k\,\theta. \tag{5}$$

Consequently

$$U = \sin k\,\theta,\ V = k \cos k\,\theta. \tag{6}$$

Since $M = q/a = q/V$, and $V = 0$ for $\theta_m \equiv \pi/2k$, θ may range between θ and θ_m. As θ increases from 0 to θ_m, the various quantities behave as follows:

1. $U = \sin k\,\theta$ increases from 0 to 1.

2. $V = a = k \cos k\,\theta$ decreases from k to 0.

3. The local speed $q = (U^2 + V^2)^{\frac{1}{2}}$ increases since $q' = (uV/q) \times (1 - k^2) > 0$ in $0 \leq \theta \leq \theta_m$. Moreover, $q(0) = k$, $q(\theta_m) = 1$.

4. The local Mach number $M = q/a$ increases from 1 to ∞.

5. The density ratio $\rho/\rho_o = C(V^2)^{1/(\gamma - 1)}$, with $C = [2/(\gamma - 1)]^{1/(\gamma - 1)}$, and ρ_o denoting the stagnation density, decreases from $[2/(\gamma + 1)]^{1/(\gamma - 1)}$ to 0. In flowing around the corner the gas is continually being expanded.

6. The pressure ratio $p/p_o = (\rho/\rho_o)^{\gamma}$ also decreases, from $[2/(\gamma+1)]^{\gamma/(\gamma-1)}$ to 0.

7. The temperature ratio $T/T_o = (p/p_o)/(\rho/\rho_o)$ decreases from $2/(\gamma+1)$ to 0.

8. The Mach angle $\mu = \arctan(V/U)$ decreases from $\pi/2$ to 0.

9. The inclination δ of the streamlines is related to θ and μ by $\delta = \theta + \mu - \pi/2$. However, $\delta' = 1 - (k\cos\mu/U)^2 = 1 - (k/q)^2 > 0$. Thus δ increases, varying between 0 and $\delta_m = (\pi/2)\,[(1/k) - 1] \approx 129^{\circ}.32$. In practice the angle δ_f of turn is frequently prescribed, and the problem consists then in the determination of M, p, etc. for the specified amount of turn. The calculations leading to the tabulated values started with the computation of U and V by means of equations (6), for equally spaced values of the polar angle θ. Next Mach angle μ and angle δ of streamline inclination were obtained. This was followed by the inversion of $\delta(\theta)$, and the direct interpolations necessary to get U, V as functions of the equi-spaced values of δ. Knowing the velocity components U, V the determination of q, M, ρ/ρ_o, p/p_o, and T/T_o was a simple matter. Wherever necessary the computed values were smoothed by differencing.

To check the tabular entries the angle δ was recalculated as function of M by means of the relationship

$$2\,\delta = \arccos(1 - 2/M^2) + k^{-1}\arccos\left[\left(\frac{2\gamma}{\gamma-1} - M^2\right)\Big/\left(\frac{2}{\gamma-1} + M^2\right)\right] - \pi \quad (7)$$

which is the integral of the differential equation

$$d\,\delta = (M^2 - 1)^{\frac{1}{2}}\,dq/q$$

$$= \frac{2}{\gamma - 1}\;\frac{[1 - (1/M^2)]^{\frac{1}{2}}}{[2/(\gamma-1)] + M^2}\;dM$$

with the initial condition $\delta = 0$ for $M = 1$. Since M becomes unbounded as δ approaches $129^{\circ}.32$ it is necessary, for large values of M, to replace $\delta(M)$ by $\delta(M^*)$, where

$$M^* = \left[\frac{(\gamma+1)\,M^2}{(\gamma-1)\,M^2 + 2}\right]^{\frac{1}{2}} \quad (8)$$

As M becomes unbounded M^* approaches $[(\gamma+1)/(\gamma-1)]^{\frac{1}{2}}$.

Next $\delta(M)$ was inverted to give M for equidistant values of δ. On comparison of these values of M with the ones previously computed the agreement was found to extend to all decimal places exhibited in the table except for an occasional deviation of one unit in the last place shown.

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δ	θ	μ	q	M	ρ/ρ_0	p/p_0	T/T_0
0.0	0.000	90.000	.41036	1.00000	.63425	.52744	.83160
0.5	18.414	72.086	.42752	1.05095	.60754	.49651	.81724
1.0	23.442	67.558	.43775	1.08194	.59140	.47808	.80838
1.5	27.068	64.432	.44639	1.10856	.57769	.46258	.80073
2.0	30.025	61.975	.45416	1.13283	.56531	.44870	.79374
2.5	32.573	59.927	.46135	1.15555	.55381	.43593	.78715
3.0	34.844	58.156	.46810	1.17718	.54296	.42399	.78087
3.5	36.911	56.589	.47452	1.19798	.53263	.41269	.77482
4.0	38.822	55.178	.48068	1.21813	.52272	.40193	.76895
4.5	40.608	53.892	.48661	1.23776	.51315	.39164	.76322
5.0	42.291	52.709	.49234	1.25697	.50388	.38175	.75761
5.5	43.889	51.611	.49790	1.27582	.49489	.37221	.75210
6.0	45.414	50.586	.50331	1.29436	.48614	.36298	.74668
6.5	46.875	49.625	.50859	1.31264	.47760	.35404	.74134
7.0	48.281	48.719	.51375	1.33070	.46924	.34537	.73606
7.5	49.639	47.861	.51880	1.34858	.46106	.33695	.73084
8.0	50.954	47.046	.52376	1.36631	.45305	.32877	.72567
8.5	52.231	46.269	.52863	1.38390	.44520	.32080	.72055
9.0	53.472	45.528	.53341	1.40136	.43750	.31302	.71548
9.5	54.682	44.818	.53811	1.41872	.42993	.30543	.71044
10.0	55.863	44.137	.54274	1.43600	.42249	.29803	.70543
10.5	57.017	43.483	.54730	1.45320	.41517	.29081	.70046
11.0	58.147	42.853	.55180	1.47034	.40797	.28375	.69551
11.5	59.255	42.245	.55624	1.48743	.40089	.27685	.69060
12.0	60.342	41.658	.56062	1.50448	.39391	.27011	.68571
12.5	61.410	41.090	.56495	1.52150	.38704	.26351	.68084
13.0	62.460	40.540	.56923	1.53850	.38028	.25706	.67599
13.5	63.492	40.008	.57345	1.55548	.37361	.25075	.67116
14.0	64.509	39.491	.57762	1.57245	.36703	.24458	.66636
14.5	65.512	38.988	.58175	1.58942	.36054	.23854	.66157
15.0	66.500	38.500	.58584	1.60639	.35414	.23263	.65679
15.5	67.475	38.025	.58989	1.62338	.34785	.22684	.65203
16.0	68.438	37.562	.59390	1.64038	.34165	.22117	.64729
16.5	69.389	37.111	.59786	1.65740	.33553	.21562	.64257
17.0	70.329	36.671	.60178	1.67444	.32949	.21018	.63786
17.5	71.259	36.241	.60567	1.69151	.32352	.20485	.63316
18.0	72.178	35.822	.60953	1.70861	.31764	.19963	.62847
18.5	73.088	35.412	.61336	1.72576	.31184	.19452	.62379
19.0	73.989	35.011	.61715	1.74296	.30611	.18952	.61913
19.5	74.881	34.619	.62091	1.76020	.30046	.18463	.61448
20.0	75.765	34.235	.62463	1.77748	.29489	.17984	.60984

SUPERSONIC FLOW OF AIR AROUND CORNERS

δ	θ	μ	q	M	ρ/ρ_o	p/p_o	T/T_o
20.5	76.640	33.860	.62832	1.79481	.28940	.17515	.60520
21.0	77.508	33.492	.63198	1.81220	.28398	.17056	.60057
21.5	78.369	33.131	.63562	1.82965	.27863	.16606	.59596
22.0	79.223	32.777	.63923	1.84717	.27335	.16166	.59137
22.5	80.070	32.430	.64281	1.86475	.26814	.15735	.58679
23.0	80.911	32.089	.64636	1.88240	.26300	.15313	.58222
23.5	81.746	31.754	.64988	1.90014	.25793	.14900	.57766
24.0	82.574	31.426	.65338	1.91795	.25293	.14496	.57310
24.5	83.397	31.103	.65685	1.93583	.24800	.14101	.56855
25.0	84.215	30.785	.66030	1.95380	.24314	.13714	.56401
25.5	85.027	30.473	.66372	1.97186	.23835	.13336	.55948
26.0	85.834	30.166	.66711	1.99000	.23363	.12966	.55496
26.5	86.636	29.864	.67048	2.00823	.22898	.12604	.55045
27.0	87.433	29.567	.67383	2.02655	.22440	.12250	.54595
27.5	88.225	29.275	.67715	2.04497	.21988	.11904	.54146
28.0	89.013	28.987	.68045	2.06350	.21542	.11566	.53698
28.5	89.796	28.704	.68373	2.08213	.21102	.11236	.53251
29.0	90.576	28.424	.68698	2.10087	.20668	.10913	.52805
29.5	91.351	28.149	.69021	2.11972	.20240	.10597	.52360
30.0	92.123	27.877	.69343	2.13868	.19818	.10288	.51916
30.5	92.890	27.610	.69662	2.15776	.19402	.09986	.51473
31.0	93.654	27.346	.69979	2.17695	.18992	.09691	.51031
31.5	94.415	27.085	.70294	2.19626	.18588	.09403	.50590
32.0	95.172	26.828	.70607	2.21570	.18191	.09122	.50148
32.5	95.925	26.575	.70917	2.23527	.17800	.08848	.49707
33.0	96.675	26.325	.71226	2.25497	.17415	.08580	.49268
33.5	97.422	26.078	.71532	2.27480	.17035	.08318	.48830
34.0	98.165	25.835	.71837	2.29476	.16661	.08063	.48394
34.5	98.906	25.594	.72140	2.31486	.16293	.07814	.47959
35.0	99.644	25.356	.72441	2.33511	.15931	.07571	.47525
35.5	100.379	25.121	.72739	2.35551	.15575	.07334	.47092
36.0	101.111	24.889	.73035	2.37605	.15224	.07103	.46659
36.5	101.840	24.660	.73330	2.39674	.14879	.06878	.46227
37.0	102.567	24.433	.73623	2.41759	.14539	.06659	.45796
37.5	103.291	24.209	.73914	2.43860	.14205	.06445	.45367
38.0	104.012	23.988	.74203	2.45978	.13876	.06236	.44939
38.5	104.731	23.769	.74490	2.48112	.13553	.06033	.44512
39.0	105.448	23.552	.74775	2.50263	.13235	.05835	.44086
39.5	106.163	23.337	.75059	2.52431	.12923	.05642	.43661
40.0	106.875	23.125	.75341	2.54617	.12616	.05454	.43237

δ	θ	μ	q	M	ρ/ρ_o	p/p_o	T/T_o
40.5	107.585	22.915	.75621	2.56821	.12314	.05271	.42815
41.0	108.292	22.708	.75899	2.59043	.12017	.05093	.42394
41.5	108.997	22.503	.76175	2.61283	.11725	.04920	.41974
42.0	109.700	22.300	.76449	2.63543	.11438	.04752	.41555
42.5	110.402	22.098	.76722	2.65823	.11156	.04588	.41137
43.0	111.102	21.898	.76993	2.68123	.10879	.04429	.40720
43.5	111.799	21.701	.77262	2.70443	.10607	.04274	.40305
44.0	112.494	21.506	.77530	2.72783	.10340	.04124	.39891
44.5	113.188	21.312	.77796	2.75144	.10078	.03978	.39478
45.0	113.880	21.120	.78060	2.77527	.09821	.03836	.39067
45.5	114.570	20.930	.78322	2.79933	.09568	.03698	.38657
46.0	115.258	20.742	.78583	2.82362	.09320	.03564	.38248
46.5	115.945	20.555	.78841	2.84813	.09077	.03434	.37841
47.0	116.630	20.370	.79098	2.87287	.08838	.03308	.37435
47.5	117.313	20.187	.79353	2.89785	.08604	.03186	.37030
48.0	117.995	20.005	.79607	2.92309	.08374	.03067	.36627
48.5	118.675	19.825	.79859	2.94858	.08149	.02952	.36225
49.0	119.354	19.646	.80110	2.97431	.07928	.02840	.35824
49.5	120.031	19.469	.80359	3.00030	.07712	.02732	.35425
50.0	120.707	19.293	.80606	3.02656	.07500	.02627	.35027
50.5	121.381	19.119	.80851	3.05310	.07292	.02525	.34631
51.0	122.054	18.946	.81095	3.07991	.07089	.02427	.34237
51.5	122.725	18.775	.81337	3.10700	.06890	.02332	.33844
52.0	123.395	18.605	.81577	3.13438	.06695	.02240	.33452
52.5	124.064	18.436	.81816	3.16206	.06504	.02151	.33061
53.0	124.731	18.269	.82053	3.19004	.06316	.02064	.32672
53.5	125.397	18.103	.82289	3.21832	.06132	.01980	.32285
54.0	126.062	17.938	.82523	3.24691	.05952	.01899	.31900
54.5	126.726	17.774	.82755	3.27582	.05777	.01821	.31516
55.0	127.388	17.612	.82986	3.30507	.05606	.01745	.31134
55.5	128.049	17.451	.83215	3.33465	.05439	.01672	.30753
56.0	128.709	17.291	.83442	3.36457	.05275	.01602	.30374
56.5	129.368	17.132	.83668	3.39483	.05114	.01534	.29997
57.0	130.026	16.974	.83892	3.42545	.04957	.01468	.29621
57.5	130.683	16.817	.84115	3.45644	.04804	.01405	.29247
58.0	131.339	16.661	.84336	3.48780	.04655	.01344	.28874
58.5	131.994	16.506	.84556	3.51954	.04509	.01285	.28503
59.0	132.647	16.353	.84774	3.55167	.04366	.01228	.28134
59.5	133.299	16.201	.84990	3.58419	.04226	.01173	.27767
60.0	133.951	16.049	.85205	3.61712	.04090	.01121	.27402

δ	θ	μ	q	M	ρ/ρ_0	p/p_0	T/T_0
60.5	134.602	15.898	.85418	3.65047	.03957	.01070	.27038
61.0	135.251	15.749	.85629	3.68425	.03827	.01021	.26676
61.5	135.899	15.601	.85839	3.71846	.03701	.00974	.26316
62.0	136.547	15.453	.86048	3.75311	.03578	.00929	.25958
62.5	137.194	15.306	.86255	3.78822	.03458	.00885	.25602
63.0	137.840	15.160	.86460	3.82379	.03341	.00843	.25248
63.5	138.485	15.015	.86663	3.85984	.03228	.00803	.24895
64.0	139.129	14.871	.86865	3.89638	.03117	.00765	.23944
64.5	139.772	14.728	.87065	3.93342	.03009	.00728	.24196
65.0	140.414	14.586	.87264	3.97097	.02903	.00692	.23849
65.5	141.056	14.444	.87462	4.00905	.02800	.00658	.23504
66.0	141.697	14.303	.87658	4.04766	.02700	.00625	.23161
66.5	142.337	14.163	.87852	4.08682	.02603	.00594	.22820
67.0	142.976	14.024	.88045	4.12654	.02509	.00564	.22481
67.5	143.614	13.886	.88236	4.16684	.02417	.00536	.22144
68.0	144.252	13.748	.88425	4.20774	.02328	.00509	.21809
68.5	144.889	13.611	.88613	4.24924	.02241	.00482	.21476
69.0	145.525	13.475	.88800	4.29136	.02157	.00456	.21145
69.5	146.160	13.340	.88985	4.33412	.02075	.00432	.20816
70.0	146.795	13.205	.89169	4.37753	.01995	.00409	.20489
70.5	147.429	13.071	.89351	4.42162	.01918	.00387	.20165
71.0	148.062	12.938	.89531	4.46640	.01843	.00366	.19843
71.5	148.695	12.805	.89709	4.51188	.01771	.00346	.19523
72.0	149.327	12.673	.89886	4.55808	.01701	.00327	.19205
72.5	149.958	12.542	.90062	4.60503	.01632	.00309	.18889
73.0	150.589	12.411	.90236	4.65275	.01566	.00292	.18575
73.5	151.219	12.281	.90409	4.70126	.01502	.00275	.18263
74.0	151.848	12.152	.90580	4.75057	.01440	.00259	.17953
74.5	152.477	12.023	.90749	4.80071	.01380	.00244	.17646
75.0	153.105	11.895	.90917	4.85170	.01322	.00230	.17341
75.5	153.733	11.767	.91083	4.90356	.01266	.00216	.17038
76.0	154.360	11.640	.91248	4.95633	.01212	.00203	.16738
76.5	154.986	11.514	.91411	5.01004	.01159	.00191	.16440
77.0	155.612	11.388	.91573	5.06470	.01108	.00179	.16144
77.5	156.238	11.262	.91733	5.12034	.01059	.00168	.15850
78.0	156.863	11.137	.91892	5.17699	.01011	.00157	.15559
78.5	157.487	11.013	.92049	5.23467	.00965	.00147	.15270
79.0	158.111	10.889	.92205	5.29343	.00921	.00138	.14983
79.5	158.734	10.766	.92359	5.35330	.00879	.00129	.14699
80.0	159.357	10.643	.92511	5.41431	.00838	.00121	.14417

δ	θ	μ	q	M	ρ/ρ_o	p/p_o	T/T_o
80.5	159.979	10.521	.92662	5.47650	.00798	.00113	.14138
81.0	160.601	10.399	.92811	5.53990	.00760	.00106	.13861
81.5	161.222	10.278	.92959	5.60454	.00723	.00099	.13586
82.0	161.843	10.157	.93106	5.67047	.00688	.00092	.13314
82.5	162.463	10.037	.93251	5.73773	.00654	.00085	.13044
83.0	163.083	9.917	.93394	5.80637	.00622	.00079	.12776
83.5	163.702	9.798	.93535	5.87643	.00591	.00074	.12511
84.0	164.321	9.679	.93675	5.94795	.00561	.00068	.12249
84.5	164.940	9.560	.93814	6.02099	.00532	.00063	.11989
85.0	165.558	9.442	.93951	6.09560	.00504	.00059	.11731
85.5	166.175	9.325	.94087	6.17183	.00477	.00055	.11476
86.0	166.793	9.207	.94221	6.24974	.00451	.00050	.11224
86.5	167.410	9.090	.94354	6.32938	.00427	.00046	.10974
87.0	168.026	8.974	.94485	6.41082	.00404	.00043	.10727
87.5	168.642	8.858	.94614	6.49412	.00382	.00040	.10482
88.0	169.258	8.742	.94742	6.57936	.00361	.00037	.10240
88.5	169.873	8.627	.94868	6.66660	.00340	.00034	.10000
89.0	170.488	8.512	.94993	6.75591	.00320	.00031	.09763
89.5	171.102	8.398	.95116	6.84738	.00301	.00029	.09529
90.0	171.717	8.283	.95238	6.94109	.00284	.00026	.09297
90.5	172.330	8.170	.95358	7.03712	.00267	.00024	.09068
91.0	172.944	8.056	.95477	7.13556	.00251	.00022	.08841
91.5	173.557	7.943	.95594	7.23652	.00235	.00020	.08617
92.0	174.170	7.830	.95710	9.34010	.00220	.00018	.08396
92.5	174.782	7.718	.95824	7.44640	.00206	.00017	.08178
93.0	175.394	7.606	.95937	7.55553	.00193	.00015	.07962
93.5	176.006	7.494	.96048	7.66760	.00181	.00014	.07749
94.0	176.618	7.382	.96157	7.78274	.00169	.00013	.07538
94.5	177.229	7.271	.96265	7.90110	.00158	.00011	.07330
95.0	177.840	7.160	.96371	8.02281	.00147	.00010	.07125
95.5	178.450	7.050	.96476	8.14802	.00137	.00010	.06923
96.0	179.061	6.939	.96579	8.27689	.00127	.00009	.06724
96.5	179.671	6.829	.96681	8.40958	.00118	.00008	.06527
97.0	180.280	6.720	.96782	8.54626	.00110	.00007	.06333
97.5	180.890	6.610	.96881	8.68712	.00102	.00006	.06142
98.0	181.499	6.501	.96978	8.83238	.00094	.00006	.05954
98.5	182.108	6.392	.97073	8.98226	.00087	.00005	.05768
99.0	182.717	6.283	.97167	9.13699	.00081	.00005	.05585
99.5	183.325	6.175	.97260	9.29678	.00075	.00004	.05405
100.0	183.933	6.067	.97351	9.46187	.00069	.00004	.05228

δ	θ	μ	q	M	ρ/ρ₀	p/p₀	T/T₀
100.5	184.541	5.959	.97441	9.63257	.00063	.00003	.05053
101.0	185.149	5.851	.97529	9.80923	.00058	.00003	.04882
101.5	185.756	5.744	.97615	9.99210	.00053	.00002	.04713
102.0	186.363	5.637	.97700	10.18154	.00049	.00002	.04547
102.5	186.970	5.530	.97783	10.37793	.00044	.00002	.04384
103.0	187.577	5.423	.97865	10.58165	.00040	.00002	.04224
103.5	188.184	5.316	.97946	10.79312	.00037	.00001	.04067
104.0	188.790	5.210	.98025	11.01282	.00033	.00001	.03912
104.5	189.396	5.104	.98102	11.24125	.00030	.00001	.03761
105.0	190.002	4.998	.98177	11.47893	.00027	.00001	.03612
105.5	190.608	4.892	.98251	11.72645	.00025	.00001	.03467
106.0	191.214	4.786	.98324	11.98444	.00022	.00001	.03324
106.5	191.819	4.681	.98395	12.25360	.00020	.00001	.03184
107.0	192.424	4.576	.98465	12.53467	.00018	.00001	.03047
107.5	193.029	4.471	.98533	12.82847	.00016	.00000	.02913
108.0	193.634	4.366	.98599	13.13589	.00014	.00000	.02782
108.5	194.239	4.261	.98664	13.45793	.00013	.00000	.02654
109.0	194.843	4.157	.98727	13.79566	.00011	.00000	.02529
109.5	195.448	4.052	.98789	14.15027	.00010	.00000	.02407
110.0	196.052	3.948	.98850	14.52307	.00009	.00000	.02288
110.5	196.656	3.844	.98909	14.91550	.00008	.00000	.02171
111.0	197.260	3.740	.98966	15.32918	.00007	.00000	.02058
111.5	197.863	3.637	.99021	15.76589	.00006	.00000	.01948
112.0	198.467	3.533	.99075	16.22763	.00005	.00000	.01841
112.5	199.070	3.430	.99128	16.71664	.00005	.00000	.01736
113.0	199.673	3.327	.99179	17.23542	.00004	.00000	.01635
113.5	200.277	3.223	.99229	17.78679	.00003	.00000	.01537
114.0	200.880	3.120	.99277	18.37395	.00003	.00000	.01442
114.5	201.483	3.017	.99323	19.00052	.00002	.00000	.01349
115.0	202.086	2.914	.99368	19.67062	.00002	.00000	.01260
115.5	202.689	2.811	.99411	20.38898	.00002	.00000	.01174
116.0	203.291	2.709	.99453	21.16104	.00001	.00000	.01092
116.5	203.894	2.606	.99493	21.99309	.00001	.00000	.01011
117.0	204.496	2.504	.99532	22.89243	.00001	.00000	.00934
117.5	205.099	2.401	.99569	23.86760	.00001	.00000	.00859
118.0	205.701	2.299	.99605	24.92866	.00001	.00000	.00788
118.5	206.303	2.197	.99639	26.08752	.00001	.00000	.00720
119.0	206.905	2.095	.99672	27.35838	.00000	.00000	.00655
119.5	207.507	1.993	.99703	28.75835	.00000	.00000	.00594
120.0	208.109	1.891	.99732	30.30824	.00000	.00000	.00535

δ	θ	μ	q	M	ρ/ρ_0	p/p_0	T/T_0
120.5	208.711	1.789	.99760	32.03356	.00000	.00000	.00479
121.0	209.313	1.687	.99787	33.96592	.00000	.00000	.00426
121.5	209.915	1.585	.99812	36.14505	.00000	.00000	.00377
122.0	210.516	1.484	.99835	38.62158	.00000	.00000	.00330
122.5	211.118	1.382	.99857	41.46095	.00000	.00000	.00286
123.0	211.720	1.280	.99877	44.74925	.00000	.00000	.00246
123.5	212.321	1.179	.99896	48.60226	.00000	.00000	.00209
124.0	212.923	1.077	.99913	53.17932	.00000	.00000	.00174
124.5	213.524	.976	.99928	58.70584	.00000	.00000	.00143
125.0	214.125	.875	.99942	65.51176	.00000	.00000	.00115
125.5	214.727	.773	.99955	74.10006	.00000	.00000	.00090
126.0	215.328	.672	.99966	85.27878	.00000	.00000	.00068
126.5	215.929	.571	.99976	100.42269	.00000	.00000	.00049
127.0	216.531	.469	.99984	122.09375	.00000	.00000	.00033
127.5	217.132	.368	.99990	155.69680	.00000	.00000	.00020
128.0	217.733	.267	.99995	214.81091	.00000	.00000	.00011
128.5	218.335	.165	.99998	346.27721	.00000	.00000	.00004
129.0	218.936	.064	1.00000	892.35828	.00000	.00000	.00001
129.32	219.32	0	1	∞	0	0	0

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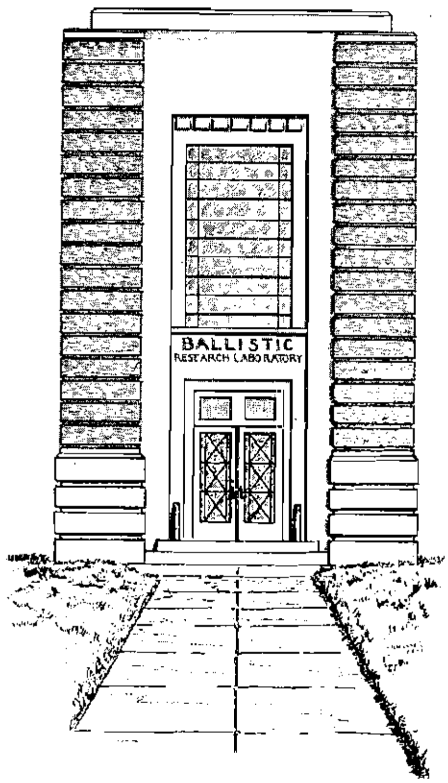
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